

ELECTRONIC FUNDAMENTALS

THEORY LESSON 8

D-C CIRCUITS

- 8-1. Simple Circuits
- 8-2. Series Circuits
- 8-3. Series Filament Circuits
- 8-4. Parallel Circuits
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RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

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Theory Lesson 8

INTRODUCTION

This lesson is one of the most important and most difficult lessons you will study in this course. Do not rush; take time enough to study it carefully. As suggested in the Introduction to this course, it would be a good idea to read through the entire lesson rapidly, just to get an idea of what it's all about. Then return to the beginning and study each paragraph carefully; make sure that you understand what is said before you go on to the next paragraph. It may be necessary to read through a paragraph several times and to examine the illustrations just as many times before you can be sure that you are ready to go ahead. Just remember that this is a tough one — so take it easy.

8-1. SIMPLE CIRCUITS

From the lessons already studied, we know that for electricity to flow, there must be a conducting path. Only then can electrons move from atom to atom to produce electric current. We know that this path must be continuous (unbroken). We call such a path a *circuit*. If the conducting path is broken at any point, the flow of current stops. For example, in Fig. 8-1a, we see a battery, a switch, and a lamp connected together. Current cannot flow because the switch is open. We call this an *open circuit*. However, in Fig. 8-1b, which shows the switch closed, current flows; the lamp lights because the circuit is complete. We call this a *closed circuit*.

If a wire is connected from one side of the battery to the other, as shown in Fig. 8-1c, no current flows through the lamp even when the switch is closed. Instead, the current flows only through the battery and the shorting wire. We call this a *short circuit*. When a good conducting path, such as the

shorting wire, produces a short circuit, it offers a very heavy load to the battery. The battery soon becomes polarized and unable to produce any useful voltage. Because of the high current that flows, excessive heat is developed, and a fire may result.

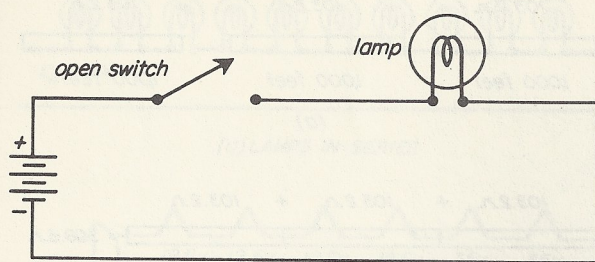
If an electric power line is shorted, the generator, which is the source of the power must be protected from the effects of a short circuit. It is protected by fuses or other devices that open the circuit when the current exceeds a safe level. Even battery circuits sometimes have fuses, as shown in Fig. 8-1d. When the current reaches a certain level, the metal link in the fuse melts, and the circuit becomes open as shown in Fig. 8-1e.

8-2. SERIES CIRCUITS

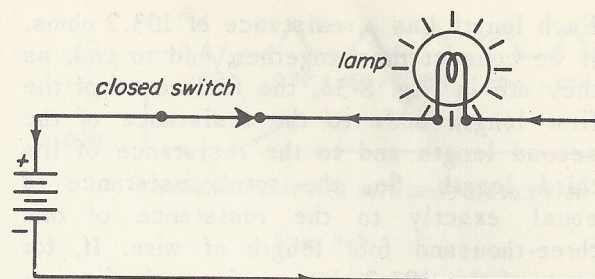
In electrical circuits, it is often necessary to connect two, three, or more resistors or other electrical units together. When these circuit parts are connected end to end, so that there is only one conducting path in which current may flow, we call it a *series circuit*. For example, in Fig. 8-2a, we find a resistor and a lamp connected in series across a battery to form a series circuit. The current flowing from the battery, through the lamp, through the resistor, and back to the battery, is the same. If we measure the current in any part of a series circuit, we find that the same current flows. For example, in the series circuit shown in Fig. 8-2b, the current flowing through the three resistors is the same. Therefore,

$$I_{R1} = I_{R2} = I_{R3}$$

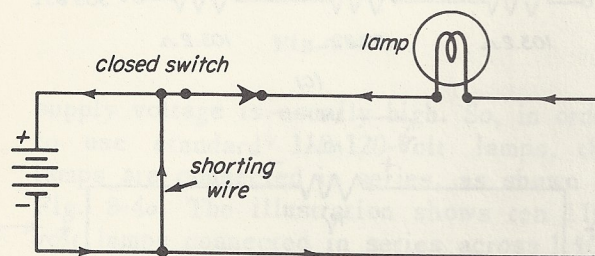
From this we may form a rule for series circuits: In a series circuit, the same current flows in each part of the circuit.



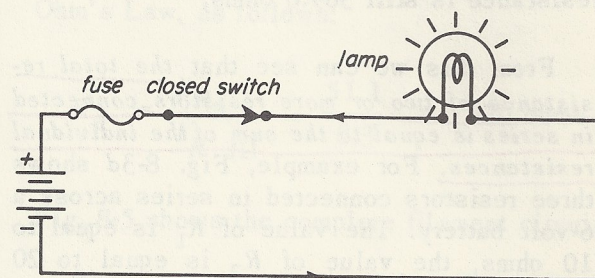
(a) AN OPEN CIRCUIT
switch open = no current



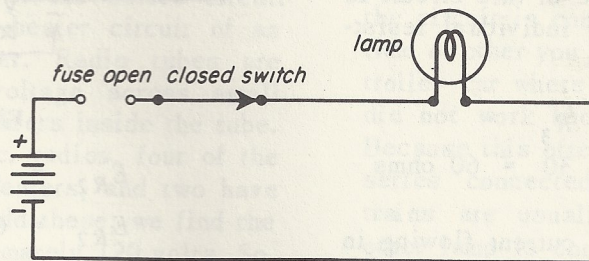
(b) A CLOSED CIRCUIT
switch closed = current flows



(c) A SHORT CIRCUIT
current flowing only in shorting wire and battery



(d) A CIRCUIT WITH A FUSE
fuse and switch closed = current flows

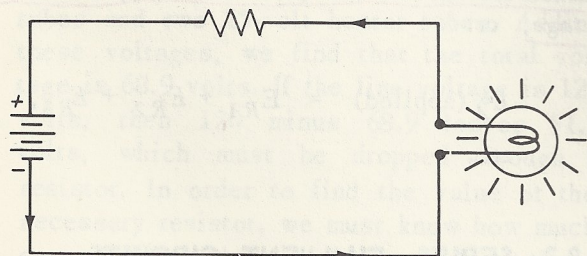


(e) A CIRCUIT WITH BLOWN FUSE
fuse open = no current flows

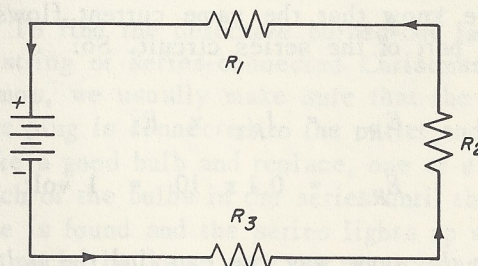
Fig. 8-1

In the last lesson, you learned that the resistance of a conductor, such as copper wire, is in proportion to the length of the conductor. For example, the resistance of one thousand feet of No. 30 copper wire is equal to 103.2 ohms. The resistance of two

thousand feet of the same wire is equal to twice 103.2 ohms, or 206.4 ohms. The resistance of three thousand feet is equal to three times 103.2 ohms, or 309.6 ohms. Suppose we have three separate one thousand-foot lengths of this wire, as shown in Fig. 8-3a.



(a) A SERIES CIRCUIT



(b) $I_{R1} = I_{R2} = I_{R3}$

Fig. 8-2

Each length has a resistance of 103.2 ohms. If we connect them together, end to end, as they are in Fig. 8-3b, the resistance of the first length adds to the resistance of the second length and to the resistance of the third length. So, the total resistance is equal exactly to the resistance of one three-thousand foot length of wire. If, for each of the 103.2-ohm sections of wire, we use 103.2-ohm resistors and connect them end to end, as shown in Fig. 8-3c, the total resistance is still 309.6 ohms.

From this we can see that the total resistance of two or more resistors connected in series is equal to the sum of the individual resistances. For example, Fig. 8-3d shows three resistors connected in series across a 6-volt battery. The value of R_1 is equal to 10 ohms, and the value of R_2 is equal to 20 ohms, and the value of R_3 is equal to 30 ohms. Without counting the internal resistance of the battery (which is normally very little), the total resistance of this circuit is equal to the sum of the individual resistances, or

$$R_t = R_1 + R_2 + R_3$$

$$R_t = 10 + 20 + 30 = 60 \text{ ohms}$$

To find the amount of current flowing in the circuit, we use Ohm's Law again. Current equals voltage divided by resistance, or:

$$I_t = \frac{E_t}{R_t}$$

$$I_t = \frac{6}{60} = 0.1 \text{ ampere}$$

We know that the same current flows in each part of the series circuit. So:

$$E_{R1} = I_{R1} \times R_1$$

$$E_{R1} = 0.1 \times 10 = 1 \text{ volt}$$

In the same way, we can find the voltage drops across R_2 and R_3 . We use the term voltage drop to mean a potential difference or a difference in voltage.

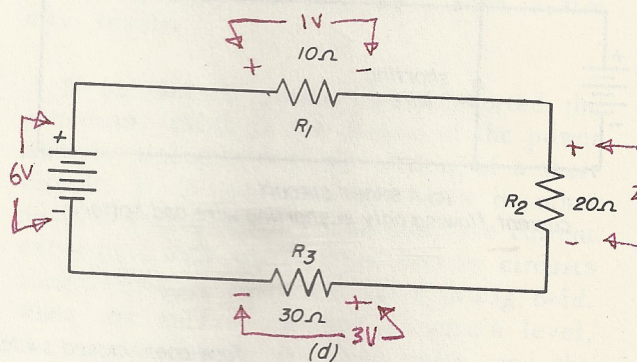
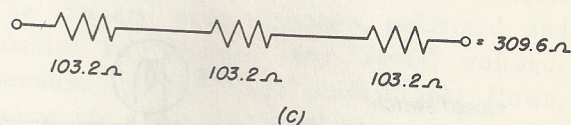
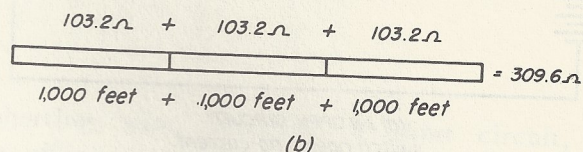
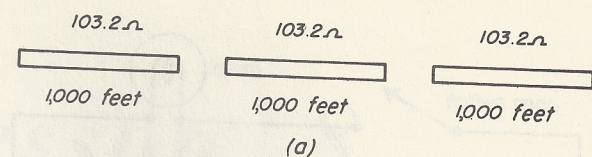


Fig. 8-3

$$E_{R2} = I_{R2} \times R_2$$

$$E_{R2} = 0.1 \times 20 = 2 \text{ volts}$$

$$E_{R3} = I_{R3} \times R_3$$

$$E_{R3} = 0.1 \times 30 = 3 \text{ volts}$$

If we add the voltage drops across R_1 , R_2 , and R_3 , we find that the sum is 6 volts, which is exactly equal to the applied voltage (battery voltage). From this, we can make another rule: The sum of the voltage drops in a series circuit is equal to the applied voltage, or:

$$E_A (\text{applied}) = E_{R1} + E_{R2} + E_{R3},$$

etc.

8-3. SERIES FILAMENT CIRCUITS

Series circuits are used in some electric-railway or trolley-car lighting systems. The

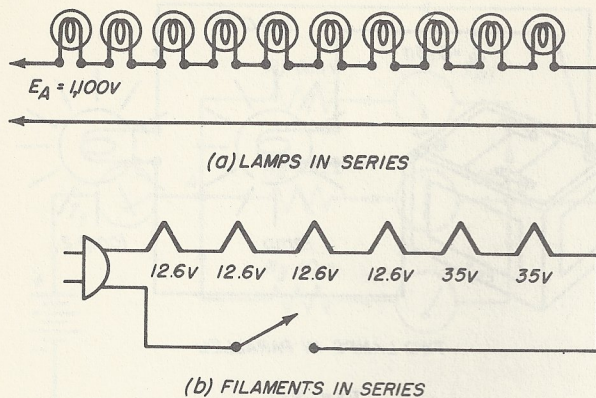


Fig. 8-4

supply voltage is usually high. So, in order to use standard 110-120-volt lamps, the lamps are connected in series, as shown in Fig. 8-4a. The illustration shows ten 110-volt lamps connected in series across 1,100 volts. The voltage drop across each lamp is 110 volts; the sum of the voltage drops across the lamps is equal to the applied voltage. Another use of the series circuit is in the filament or heater circuit of an a.c.-d.c. radio receiver. Radio tubes are heated by applying voltage across small electric filaments or heaters inside the tube. In many 6-tube a.c.-d.c. radios, four of the tubes have 12.6 volt heaters, and two have 35-volt heaters. If we add these, we find the total voltage is approximately 120 volts. So, the heaters of these tubes are normally connected in series, as shown in Fig. 8-4b.

In some cases, the heater voltages of the tubes used in an a.c.-d.c. receiver do not add up to the line voltage. In such cases, it is necessary to place a resistor in series with the filaments in order to drop the voltage to the amount needed to heat the filaments. For example, some of the earlier a.c.-d.c. radios used three 6.3-volt heater tubes and two 25-volt heater tubes. Adding these voltages, we find that the total voltage is 68.9 volts. If the line voltage is 120 volts, then 120 minus 68.9 leaves 51.1 volts, which must be dropped through a resistor. In order to find the value of the necessary resistor, we must know how much current flows through the heaters of these tubes. By looking them up in a tube manual, we find that the current for each tube is 300 ma, or 0.3 amperes. With this information,

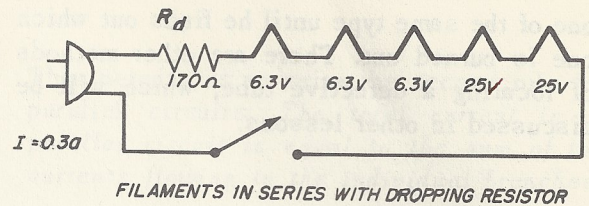


Fig. 8-5

we can now find the value of the voltage-dropping resistor, or filament-dropping resistor, as some servicemen call it. We use Ohm's Law, as follows:

$$R_d = \frac{E_{Rd}}{I_{R_{fil}}} = \frac{51.1}{0.3} = 170 \text{ ohms}$$

Fig. 8-5 shows the complete filament circuit.

When any part of a series circuit burns out, is removed, or for any reason becomes open-circuited, current stops flowing in the entire circuit. Current cannot flow unless the circuit is complete. For example, sometime or other you may have been in a train or trolley car where one whole series of lights did not work because one was burned out. Because this often happens where lights are series connected, the lights in cars and trains are usually arranged so that every other lamp is connected to the same series string. In this way, light is still evenly distributed, even when one series is open. You may have seen lights series-connected on a Christmas tree. Then, when one light became loosened or burned out, all the lights in the series went out. In any radio that uses a series filament or heater circuit, when one tube burns out or is removed from its socket, all of the tubes stop glowing because the circuit is broken.

To find the defective burned-out lamp in a string of series-connected Christmas tree lamps, we usually make sure that the electric plug is connected to the outlet and then take a good bulb and replace, one at a time, each of the bulbs in the series until the bad one is found and the series lights up again. In much the same way, a serviceman who finds an open filament circuit in an a.c.-d.c. series-connected circuit may replace each of the tubes of the set, one at a time, with

one of the same type until he finds out which one is burned out. There are other methods of locating a defective tube, which will be discussed in other lessons.

8-4. PARALLEL CIRCUITS

In Fig. 8-6, a lamp is connected to the terminals of a 6-volt storage battery. The current flowing in this simple circuit is 0.15 ampere. The voltage across the lamp is 6 volts. If we wish, we may calculate the resistance of the filament in the lamp (when hot) by using Ohm's Law.

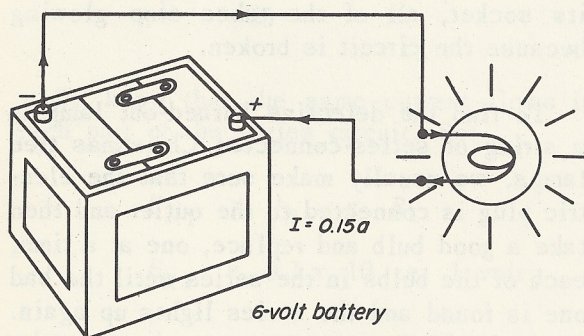
$$R = \frac{E}{I}$$

$$R = 6 \div 0.15$$

$$R = 40 \text{ ohms}$$

This circuit is called a *simple circuit*. It is *not* a series circuit. The lamp is considered to be across the terminals or in parallel with the terminals of the storage battery and not in series with them. This is an important fact.

Let us connect another lamp to the battery, as shown in Fig. 8-7. This lamp draws 0.25 ampere. The current flowing through lamp #1 flows from the negative terminal of the battery through the connecting wire to the lamp, then through the connecting wire to the positive terminal of the battery. The



A SIMPLE CIRCUIT

Fig. 8-6

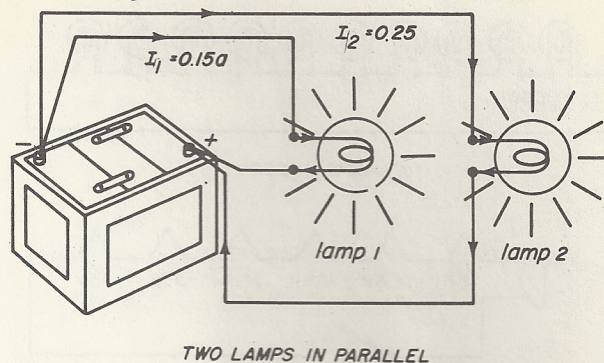


Fig. 8-7

current flowing through lamp #2 flows through a connecting wire from the negative terminal of the battery, through the lamp, and through the connecting wire to the positive terminal of the battery. The current in lamp #1 is not the same as the current flowing in lamp #2. The total current drawn from the battery is equal to the current flowing through lamp #1 added to the current flowing through lamp #2. Therefore:

$$I_t = I_1 + I_2$$

$$I_t = 0.15 + 0.25 = 0.40 \text{ ampere}$$

Lamp #2 has the same 6 volts across it as lamp #1 has. So, we may calculate the resistance of lamp #2 (when hot) by:

$$R_{L2} = \frac{E}{I_2}$$

$$R_{L2} = \frac{6}{0.25} = 24 \text{ ohms}$$

Because there are two separate paths in which current flows, this is not a series circuit. Instead, it is called a *parallel circuit*. A *parallel circuit* is one that has two or more branches (paths) where one terminal from each branch is connected electrically to a common potential of the same polarity and where the remaining terminal of each branch is connected electrically to a common potential of opposite polarity.

In Fig. 8-8, three resistors are connected in parallel. The voltage between points A and B is equal to the voltage of the battery —

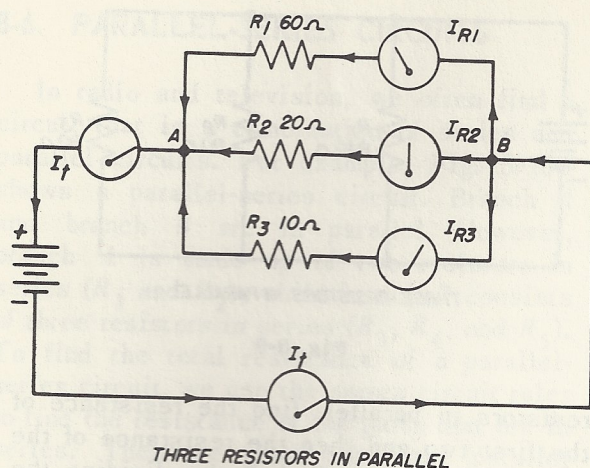


Fig. 8-8

6 volts. So, the voltage across R_1 is the same as the voltage across R_2 and the same as the voltage across R_3 . This enables us to write our first rule for parallel circuits: *The voltage across one branch of a parallel circuit is the same as the voltage across any other branch and is equal to the applied voltage.*

Using Ohm's Law, we find the current flowing in each of the three parallel branches as follows:

$$I_{R1} = \frac{E_{R1}}{R_1} = \frac{6}{60} = 0.1 \text{ ampere}$$

$$I_{R2} = \frac{E_{R2}}{R_2} = \frac{6}{20} = 0.3 \text{ ampere}$$

$$I_{R3} = \frac{E_{R3}}{R_3} = \frac{6}{10} = 0.6 \text{ ampere}$$

The current flowing from the negative terminal of the battery to point B and the current flowing from point A to the positive terminal of the battery is the total current and is equal to the sum of the branch currents. Thus:

$$I_t = I_{R1} + I_{R2} + I_{R3}$$

$$I_t = 0.1 + 0.3 + 0.6$$

$$= 1.0 \text{ ampere}$$

This permits us to write the second rule for parallel circuits: *The total current in a parallel circuit is equal to the sum of the currents flowing in the individual branches.*

8.5. TOTAL RESISTANCE OF A PARALLEL CIRCUIT

Knowing the total current flowing at the terminals of the battery, we can use Ohm's Law to calculate the total resistance between points A and B:

$$R_t = \frac{E}{I_t} = \frac{6}{1} = 6 \text{ ohms}$$

So, a 60-ohm, a 20-ohm, and a 10-ohm resistor connected in parallel have a total resistance less than the value of any one of the resistors by itself. To find the total resistance of two or more resistors connected in parallel, we cannot add them as we do when they are connected in series. Instead, we use a different formula.

Of course, we know that the total resistance of a parallel circuit is equal to the total voltage divided by the total current, but this is not very helpful when we want to know, for example, what value of resistance we get when we combine two resistors in parallel. One formula that we can use, once in a while, says: *The total resistance of equal resistors in parallel is equal to the value of one of the resistors divided by the number of them connected in parallel.* For example, two 500-ohm resistors connected in parallel have a resistance equal to 500 (the value of one of the equal resistors in parallel), divided by 2 (the number of resistors), or 250 ohms. We find the total resistance of four 600-ohm resistors in parallel similarly:

$$R_t = \frac{600}{4} = 150 \text{ ohms}$$

Of course, this formula can be used only when we connect resistors of equal value in parallel.

Another formula we can use is: *The total resistance of any two resistors connected in parallel is equal to their product divided by their sum.* Or:

$$R_t = \frac{\text{Product}}{\text{sum}} = \frac{R_1 \times R_2}{R_1 + R_2}$$

For example, let R_1 equal 20 ohms and R_2 equal 60 ohms. Then:

$$\begin{aligned} R_t &= \frac{R_1 \times R_2}{R_1 + R_2} = \frac{20 \times 60}{20 + 60} \\ &= \frac{1200}{80} = 15 \text{ ohms} \end{aligned}$$

This is the easiest and most popular method used to find the total resistance of resistors connected in parallel. It may be used to find the total resistance of three or more resistors connected in parallel by working in two or more steps. For example, Fig. 8-9 shows three resistors connected in parallel. To find the total resistance of this circuit, we find the resistance of two of the parallel resistors first. Then, we find the total resistance by finding the product of this resistance and the resistance of the remaining resistor over the sum of the two resistances.

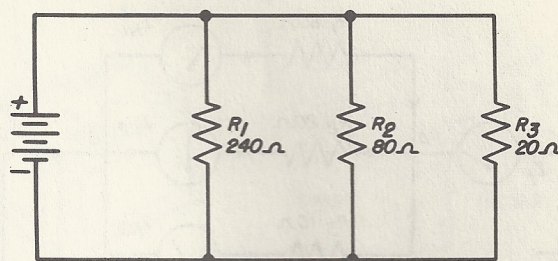
For example:

$$\begin{aligned} R_{1\&2} &= \frac{R_1 \times R_2}{R_1 + R_2} = \frac{240 \times 80}{240 + 80} \\ &= \frac{19,200}{320} = 60 \text{ ohms} \end{aligned}$$

then:

$$\begin{aligned} R_t &= \frac{R_{1\&2} \times R_3}{R_{1\&2} + R_3} = \frac{60 \times 20}{60 + 20} \\ &= \frac{1,200}{80} = 15 \text{ ohms} \end{aligned}$$

To find the total resistance of four



THREE RESISTORS IN PARALLEL

Fig. 8-9

resistors in parallel, find the resistance of the first two and then the resistance of the second two. Then find R_t by dividing the product of the two answers by the sum of the two answers.

Reciprocal Method. The total resistance of two or more resistors connected in parallel may be found by still another method. We call it the *reciprocal method*. The *reciprocal* of any value or number, as you know, is equal to 1 divided by the value or the number. For example, the reciprocal of 25 is equal to 1 divided by 25 ($1/25$), which equals 0.04. Using the reciprocal method, R_t is equal to:

$$\frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}, \text{ etc.}}$$

To see how this formula works, let's use it to find the total resistance of the three resistors in Fig. 8-9, the same value that we just found by the product-over-the-sum method.

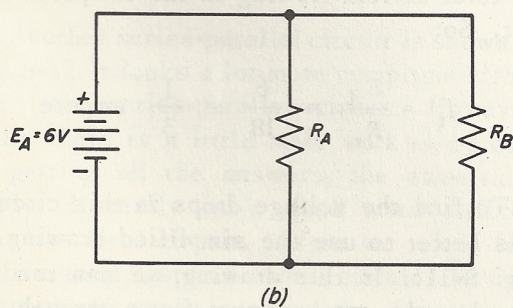
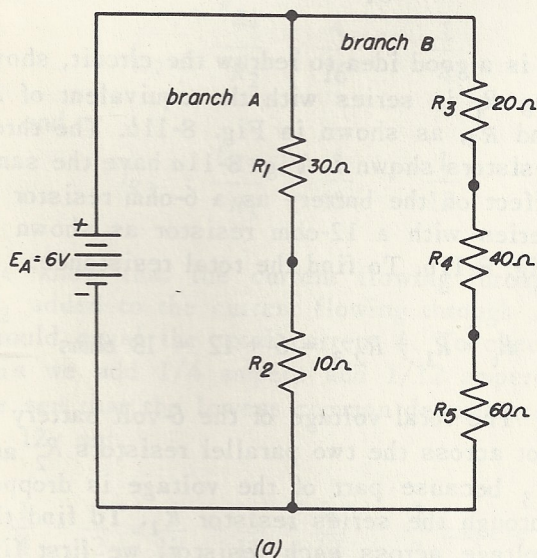
$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = \frac{1}{\frac{1}{240} + \frac{1}{80} + \frac{1}{20}}$$

Next we must find the common denominator, which is 240:

$$\begin{aligned} R_t &= \frac{1}{\frac{1}{240} + \frac{3}{240} + \frac{12}{240}} = \frac{1}{\frac{16}{240}} \\ &= 1 \times \frac{240}{16} = 15 \text{ ohms} \end{aligned}$$

8-6. PARALLEL-SERIES CIRCUITS

In radio and television, we often find a circuit that is a combination of series and parallel circuits. For example, Fig. 8-10a shows a parallel-series circuit. Branch A and branch B are in parallel. However, branch A is made up of two resistors in series (R_1 and R_2), while branch B consists of three resistors in series (R_3 , R_4 , and R_5). To find the total resistance of a parallel-series circuit, we use the series circuit rules to find the resistance of the parts that are in series. Then we must apply the parallel circuit rules to find the resistance of the parallel branches. The order in which these rules are applied depends upon what is known about the circuit. For example, if the value of each resistor is given, as in the circuit shown in Fig. 8-10a, we first find the total series resistance in each branch before we find the total resistance of the parallel branches. So:



PARALLEL-SERIES CIRCUIT

Fig. 8-10

$$R_{\text{Branch A}} = R_1 + R_2 = 30 + 10 = 40 \text{ ohms}$$

$$R_{\text{Branch B}} = R_3 + R_4 + R_5 = 20 + 40 + 60 = 120 \text{ ohms}$$

Fig. 8-10b shows the resistance of each branch as a single resistance. To find the total resistance of the two branches we use the product over sum method. So:

$$R_t = \frac{R_{\text{Branch A}} \times R_{\text{Branch B}}}{R_{\text{Branch A}} + R_{\text{Branch B}}} = \frac{40 \times 120}{40 + 120} = \frac{4800}{160} = 30 \text{ ohms}$$

Let's take another look at the circuit shown in Fig. 8-10a. The voltage of the battery is 6 volts. From the drawing and from the parallel circuit rules, we know that the total voltage (6 volts) appears across Branch A and across Branch B. However the total voltage does not appear across either R_1 or R_2 or across any one of the resistors in Branch B. For example, part of the 6-volts appears across R_1 . The rest of the 6-volts appears across R_2 . To know how much is across each resistor, it is necessary to know first how much current flows in Branch A. To find this, we use Ohm's Law. So:

$$I_A = \frac{E_A}{R_A} = \frac{6}{40} = 0.15 \text{ ampere}$$

Therefore, the current flowing in Branch A and resistors R_1 and R_2 is equal to 0.15 amperes. To find the voltage across R_1 , we use Ohm's Law:

$$E_{R1} = I_{R1} \times R_1 = 0.15 \times 30 = 4.5 \text{ volts}$$

and to find the voltage across R_2 :

$$E_{R2} = I_{R2} \times R_2 = 0.15 \times 10 = 1.5 \text{ volts}$$

In the same way, we can find the voltages across R_3 , R_4 and R_5 in Branch B. First we

must find the current flowing in Branch *B*:

$$I_B = \frac{E_B}{R_B} = \frac{6}{120} = 0.05 \text{ ampere}$$

Therefore, the current flowing through Branch *B* and resistors R_3 , R_4 , and R_5 equals 0.05 ampere. So:

$$E_{R3} = I_{R3} \times R_3 = 0.05 \times 20 = 1 \text{ volt}$$

$$E_{R4} = I_{R4} \times R_4 = 0.05 \times 40 = 2 \text{ volts}$$

$$E_{R5} = I_{R5} \times R_5 = 0.05 \times 60 = 3 \text{ volts}$$

We can check our answer by adding E_{R3} , E_{R4} , and E_{R5} :

$$1 + 2 + 3 = 6 \text{ volts}$$

We know the answer is right when the sum of the voltage drops of the branch is equal to the voltage across the branch.

There are many kinds of parallel-series circuits; therefore a general order of steps for solving all such circuits cannot be given. Much depends upon the particular circuit and the information available about the circuit. However, most of these circuits may be solved by applying Ohm's Law and the rules for series and parallel circuits.

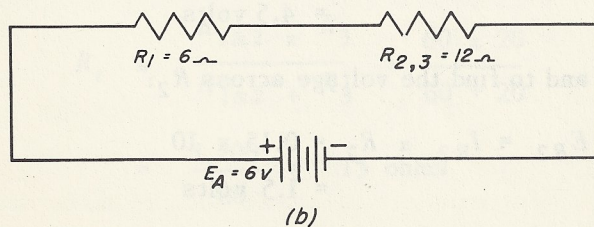
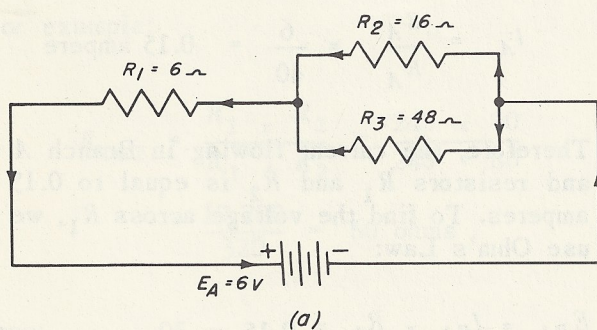


Fig. 8-11

8-7. SERIES-PARALLEL CIRCUITS

A series-parallel circuit is made up of one or more groups of parallel resistors in series with each other or in series with one or more single resistors. Fig. 8-11a shows the simplest form of series-parallel circuit. It shows a single resistor (R_1) in series with two resistors (R_2 and R_3) in parallel. To complete the circuit, this combination is connected to the terminals of a 6-volt battery. To find the total resistance offered by these three resistors, we need to apply, once again, the rules for both series and parallel circuits. To begin, we must find the equivalent resistance of 16 ohms in parallel with 48 ohms. So:

$$\begin{aligned} R_{2,3} &= \frac{R_2 \times R_3}{R_2 + R_3} = \frac{16 \times 48}{16 + 48} \\ &= \frac{768}{64} = 12 \text{ ohms} \end{aligned}$$

It is a good idea to redraw the circuit, showing R_1 in series with the equivalent of R_2 and R_3 , as shown in Fig. 8-11b. The three resistors shown in Fig. 8-11a have the same effect on the battery as a 6-ohm resistor in series with a 12-ohm resistor as shown in Fig. 8-11b. To find the total resistance:

$$R_t = R_1 + R_{2,3} = 6 + 12 = 18 \text{ ohms}$$

The total voltage of the 6-volt battery is not across the two parallel resistors R_2 and R_3 because part of the voltage is dropped through the series resistor R_1 . To find the voltage across each resistor, we first find the total current flowing in the complete circuit. So:

$$I_t = \frac{E_A}{R_t} = \frac{6}{18} = \frac{1}{3} \text{ ampere}$$

To find the voltage drops in this circuit, it is better to use the simplified drawing in Fig. 8-11b. In this drawing, we can readily see that the total current flows through R_1 and the equivalent resistance of R_2 and R_3 . Therefore,

$$E_{R_1} = I_{R_1} \times R_1 = \frac{1}{3} \times 6 = 2 \text{ volts}$$

To find the voltage across the parallel pair, we could just subtract the voltage across R_1 from the applied voltage ($6 - 2 = 4$ volts). However, to prove it, we use Ohm's Law:

$$E_{R_{2,3}} = I_{R_{2,3}} \times R_{2,3} = \frac{1}{3} \times 12 = 4 \text{ volts}$$

Looking at Fig. 8-11a, we know that the current travels from the negative terminal of the battery and divides, part going through R_2 and the rest going through R_3 . The sum of these two currents flows through R_1 and returns to the positive terminal of the battery. To find how much current flows through R_2 and how much current flows through R_3 , we can again use Ohm's Law:

$$I_{R_2} = \frac{E_{R_2}}{R_2} = \frac{4}{16} = \frac{1}{4}$$

and

$$I_{R_3} = \frac{E_{R_3}}{R_3} = \frac{4}{48} = \frac{1}{12}$$

We know that the current flowing through R_2 added to the current flowing through R_3 should equal the total current I_t . To check this we add $1/4$ ampere and $1/12$ ampere. We see that the lowest common denominator is 12, so:

$$\frac{1}{4} + \frac{1}{12} = \frac{3}{12} + \frac{1}{12} = \frac{4}{12} = \frac{1}{3} \text{ ampere}$$

Another series-parallel circuit is shown in Fig. 8-12. It looks a lot more complicated than the first series-parallel circuit. However, while there is a little more work to be done in getting all the answers, the same rules apply; it really isn't much more difficult than the first circuit. Before we try to find out the total resistance of a circuit like this, it is necessary to examine the circuit carefully and to lay out a plan of action. To find

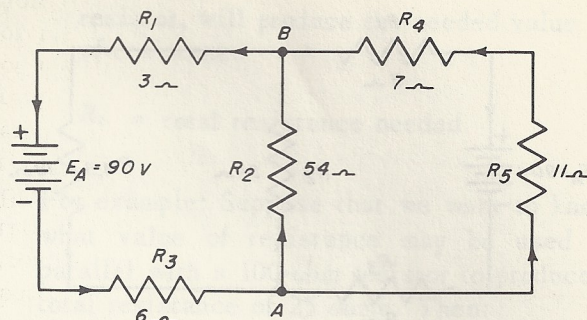


Fig. 8-12

the total resistance of a series-parallel circuit, where all of the individual resistor values are known, it is usually best to start working with the resistors farthest away from the source of voltage. Let's see why this is so. If we examine the path of current flow from the negative electrode of the battery, we find that current flows through R_3 and divides at point A; part of it flows through R_2 and the rest flows through R_5 and R_4 . These two currents come together at point B and flow through R_1 to the positive terminal of the battery. So, if we want to treat R_1 , R_2 , and R_3 as a series circuit, whose total resistance must be found first, we find that we cannot. We know that the same current flows through each part in a series circuit. We also know that R_2 carries only part of the current flowing through R_1 and R_3 . Therefore, R_1 , R_2 , and R_3 do not make a series circuit. However, we do know that the current divides, part flowing through R_2 and the rest through R_5 and R_4 . It looks therefore, as if R_2 and the combination of R_4 and R_5 are in parallel, which is the case. This being so, it is necessary to find the equivalent resistance of these two parallel branches. To do this, we must first find the total value of R_4 and R_5 in series. This brings us back to our first statement, that we usually start with the resistors farthest from the source of voltage. These resistors are R_4 and R_5 . Therefore:

$$R_{4,5} = R_4 + R_5 = 7 + 11 = 18 \text{ ohms}$$

At this point, it is a good idea to make a simplified drawing like the one as shown in

must find the current flowing in Branch B :

$$I_B = \frac{E_B}{R_B} = \frac{6}{120} = 0.05 \text{ ampere}$$

Therefore, the current flowing through Branch B and resistors R_3 , R_4 , and R_5 equals 0.05 ampere. So:

$$E_{R3} = I_{R3} \times R_3 = 0.05 \times 20 = 1 \text{ volt}$$

$$E_{R4} = I_{R4} \times R_4 = 0.05 \times 40 = 2 \text{ volts}$$

$$E_{R5} = I_{R5} \times R_5 = 0.05 \times 60 = 3 \text{ volts}$$

We can check our answer by adding E_{R3} , E_{R4} , and E_{R5} :

$$1 + 2 + 3 = 6 \text{ volts}$$

We know the answer is right when the sum of the voltage drops of the branch is equal to the voltage across the branch.

There are many kinds of parallel-series circuits; therefore a general order of steps for solving all such circuits cannot be given. Much depends upon the particular circuit and the information available about the circuit. However, most of these circuits may be solved by applying Ohm's Law and the rules for series and parallel circuits.

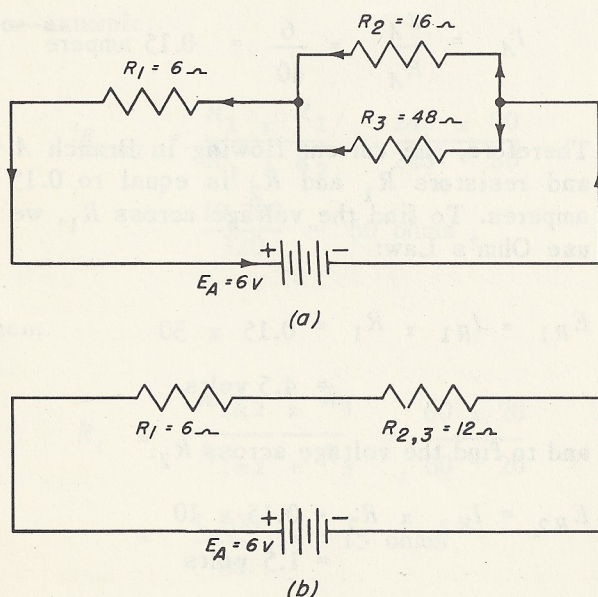


Fig. 8-11

8-7. SERIES-PARALLEL CIRCUITS

A series-parallel circuit is made up of one or more groups of parallel resistors in series with each other or in series with one or more single resistors. Fig. 8-11a shows the simplest form of series-parallel circuit. It shows a single resistor (R_1) in series with two resistors (R_2 and R_3) in parallel. To complete the circuit, this combination is connected to the terminals of a 6-volt battery. To find the total resistance offered by these three resistors, we need to apply, once again, the rules for both series and parallel circuits. To begin, we must find the equivalent resistance of 16 ohms in parallel with 48 ohms. So:

$$\begin{aligned} R_{2,3} &= \frac{R_2 \times R_3}{R_2 + R_3} = \frac{16 \times 48}{16 + 48} \\ &= \frac{768}{64} = 12 \text{ ohms} \end{aligned}$$

It is a good idea to redraw the circuit, showing R_1 in series with the equivalent of R_2 and R_3 , as shown in Fig. 8-11b. The three resistors shown in Fig. 8-11a have the same effect on the battery as a 6-ohm resistor in series with a 12-ohm resistor as shown in Fig. 8-11b. To find the total resistance:

$$R_t = R_1 + R_{2,3} = 6 + 12 = 18 \text{ ohms}$$

The total voltage of the 6-volt battery is not across the two parallel resistors R_2 and R_3 because part of the voltage is dropped through the series resistor R_1 . To find the voltage across each resistor, we first find the total current flowing in the complete circuit. So:

$$I_t = \frac{E_A}{R_t} = \frac{6}{18} = \frac{1}{3} \text{ ampere}$$

To find the voltage drops in this circuit, it is better to use the simplified drawing in Fig. 8-11b. In this drawing, we can readily see that the total current flows through R_1 and the equivalent resistance of R_2 and R_3 . Therefore,

$$E_{R1} = I_{R1} \times R_1 = \frac{1}{3} \times 6 = 2 \text{ volts}$$

To find the voltage across the parallel pair, we could just subtract the voltage across R_1 from the applied voltage ($6 - 2 = 4$ volts). However, to prove it, we use Ohm's Law:

$$E_{R2,3} = I_{R2,3} \times R_{2,3} = \frac{1}{3} \times 12 = 4 \text{ volts}$$

Looking at Fig. 8-11a, we know that the current travels from the negative terminal of the battery and divides, part going through R_2 and the rest going through R_3 . The sum of these two currents flows through R_1 and returns to the positive terminal of the battery. To find how much current flows through R_2 and how much current flows through R_3 , we can again use Ohm's Law:

$$I_{R2} = \frac{E_{R2}}{R_2} = \frac{4}{16} = \frac{1}{4}$$

and

$$I_{R3} = \frac{E_{R3}}{R_3} = \frac{4}{48} = \frac{1}{12}$$

We know that the current flowing through R_2 added to the current flowing through R_3 should equal the total current I_t . To check this we add $1/4$ ampere and $1/12$ ampere. We see that the lowest common denominator is 12, so:

$$\frac{1}{4} + \frac{1}{12} = \frac{3}{12} + \frac{1}{12} = \frac{4}{12} = \frac{1}{3} \text{ ampere}$$

Another series-parallel circuit is shown in Fig. 8-12. It looks a lot more complicated than the first series-parallel circuit. However, while there is a little more work to be done in getting all the answers, the same rules apply; it really isn't much more difficult than the first circuit. Before we try to find out the total resistance of a circuit like this, it is necessary to examine the circuit carefully and to lay out a plan of action. To find

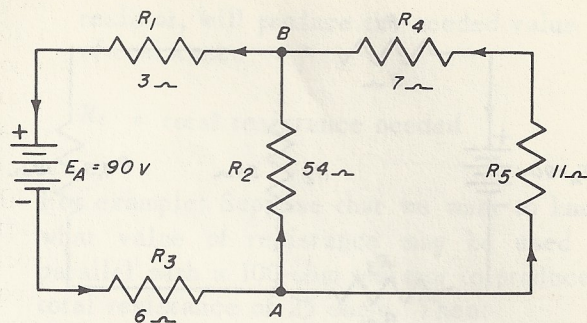


Fig. 8-12

the total resistance of a series-parallel circuit, where all of the individual resistor values are known, it is usually best to start working with the resistors farthest away from the source of voltage. Let's see why this is so. If we examine the path of current flow from the negative electrode of the battery, we find that current flows through R_3 and divides at point A; part of it flows through R_2 and the rest flows through R_5 and R_4 . These two currents come together at point B and flow through R_1 to the positive terminal of the battery. So, if we want to treat R_1 , R_2 , and R_3 as a series circuit, whose total resistance must be found first, we find that we cannot. We know that the same current flows through each part in a series circuit. We also know that R_2 carries only part of the current flowing through R_1 and R_3 . Therefore, R_1 , R_2 , and R_3 do not make a series circuit. However, we do know that the current divides, part flowing through R_2 and the rest through R_5 and R_4 . It looks therefore, as if R_2 and the combination of R_4 and R_5 are in parallel, which is the case. This being so, it is necessary to find the equivalent resistance of these two parallel branches. To do this, we must first find the total value of R_4 and R_5 in series. This brings us back to our first statement, that we usually start with the resistors farthest from the source of voltage. These resistors are R_4 and R_5 . Therefore:

$$R_{4,5} = R_4 + R_5 = 7 + 11 = 18 \text{ ohms}$$

At this point, it is a good idea to make a simplified drawing like the one as shown in

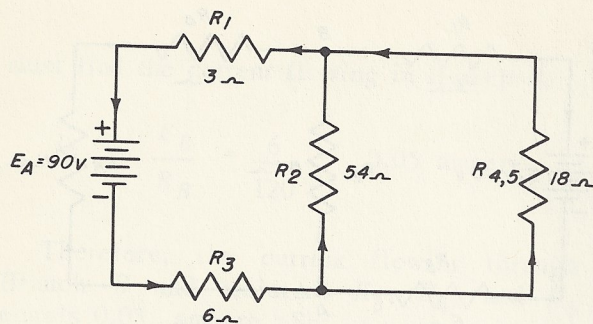


Fig. 8-13

Fig. 8-13. With such a drawing, we can see that the next step is to find the equivalent resistance of 54 ohms in parallel with 18 ohms: So:

$$R_{2,4,5} = \frac{R_2 \times R_{4,5}}{R_2 + R_{4,5}} = \frac{54 \times 18}{54 + 18} = \frac{972}{72} = 13.5 \text{ ohms}$$

Again, redraw the circuit to look like the one shown in Fig. 8-14. Now we can see that all that remains is to add three resistance values to get R_t . So:

$$R_t = R_1 + R_{2,4,5} + R_3 = 3 + 13.5 + 6 = 22.5 \text{ ohms}$$

To find the total current, we use Ohm's Law:

$$I_t = \frac{E_A}{R_t} = \frac{90}{22.5} = 4 \text{ amperes}$$

At this point, it may become a little easier to understand why we should use the simplified drawings shown in Fig. 8-13 and 8-14. Suppose we want to know the voltage drops across each resistor in the circuit shown in Fig. 8-12. By using Fig. 8-14 it is easier to see that the 90 volts of the battery is divided into three parts. One part is across R_1 , another part is across the equivalent resistance of $R_{2,4,5}$ and still another part is across R_3 . It is also easier to see that the total current (I_t) flows through R_1 and the combination of $R_{2,4,5}$ and R_3 . We must find these voltage drops by using Ohm's Law:

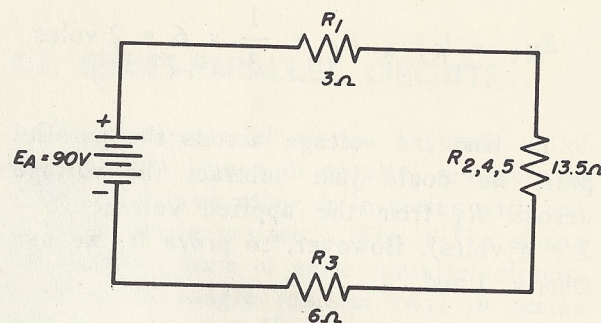


Fig. 8-14

$$E_{R1} = I_{R1} \times R_1 = 4 \times 3 = 12 \text{ volts}$$

$$E_{R2,4,5} = I_{R2,4,5} \times R_{2,4,5} = 4 \times 13.5 = 54 \text{ volts}$$

$$E_{R3} = I_{R3} \times R_3 = 4 \times 6 = 24 \text{ volts}$$

Adding these voltages, we find that $12 + 54 + 24$ exactly equal the 90 volts of the battery.

Let's shift back to Fig. 8-13. We find a simple parallel combination of 54 ohms and 18 ohms. The voltage across each branch is the same. This is a very important point to remember, so that at some time or other you won't be tempted to count the voltage across parallel branches more than once. To find the current flowing in each of these parallel branches, we use Ohm's Law:

$$I_{R2} = \frac{E_{R2}}{R_2} = \frac{54}{54} = 1 \text{ ampere}$$

We can easily find the remaining current flowing through the combination of $E_{4,5}$ by subtracting the I_{R2} from the I_t ($4 - 1 = 3$ amperes). However, we can check our work by calculating current with Ohm's Law:

$$I_{R4,5} = \frac{E_{R4,5}}{R_{4,5}} = \frac{54}{18} = 3 \text{ amperes}$$

To find the voltage drops across R_4 and R_5 , we apply Ohm's Law again:

$$E_{R4} = I_{R4} \times R_4 = 3 \times 7 = 21 \text{ volts}$$

$$E_{R5} = I_{R5} \times R_5 = 3 \times 11 = 33 \text{ volts}$$

Checking, we find that $21 + 33 = 54$ volts, which is the amount we found across the parallel branches.

8-8. COMBINING RESISTORS

Servicemen sometimes find it necessary to combine two or more resistors to get a needed resistance value. Sometimes this is done by connecting two resistors in series to add their values. For example, if a 1,500-ohm resistor is needed and we have a 1,000-ohm resistor and a 500-ohm resistor, by connecting them in series we get a total resistance of 1,500 ohms. In other cases, resistors are connected in parallel to obtain a needed value. For example, two 3,000-ohm resistors connected in parallel make:

$$R = \frac{3,000}{2} = 1,500 \text{ ohms}$$

Sometimes a radioman has a resistor of a certain value and he wants to know what value of resistance may be connected in parallel with this resistor to produce a needed amount of resistance. In such cases, the following formula is used:

$$R_2 = \frac{R_1 \times R_t}{R_1 - R_t}$$

where:

R_1 = resistance of first resistor

R_2 = resistance of the resistor that, when placed in parallel with the first

resistor, will produce the needed value of resistance

R_t = total resistance needed

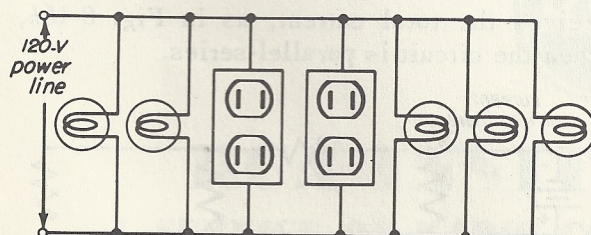
For example: Suppose that we want to know what value of resistance may be used in parallel with a 100-ohm resistor to produce a total resistance of 25 ohms. Then:

$$\begin{aligned} R_2 &= \frac{R_1 \times R_t}{R_1 - R_t} = \frac{100 \times 25}{100 - 25} \\ &= \frac{2500}{75} = 33\text{-}1/3 \text{ ohms.} \end{aligned}$$

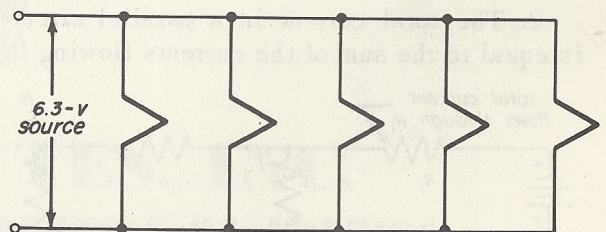
So, a 33-1/3-ohm resistor placed in parallel with a 100-ohm resistor produces a total resistance of 25 ohms.

8-9. CIRCUIT APPLICATIONS

Parallel circuits are widely used in supplying electrical power and in designing radio and television receivers. For example, most house wiring makes use of the parallel circuit. Fig. 8-15a shows that electric outlets and light sockets are connected in parallel across the power line. Most a-c radio and television receivers have parallel circuits supplying the heaters or filaments. A typical heater circuit is shown in Fig. 8-15b. One advantage of a parallel circuit is that if one lamp or tube burns out, the remaining lamps or tubes still receive power and continue to operate. For example, some Christmas tree lights are connected



(a) PARALLEL LIGHTING AND OUTLET CIRCUIT



(b) PARALLEL FILAMENT CIRCUIT

Fig. 8-15

in parallel. When the lights are so connected, it is easy to spot a burned-out light, because it just doesn't glow.

One disadvantage of parallel circuits in homes is that too many lamps or pieces of electrical apparatus may be connected to the circuit at the same time, so that too great a load is placed on the line. When this happens, more current may be drawn than the wiring is supposed to carry. If the circuit has fuses of the proper size, one or more fuses may open up. This protects the power line and even the house. For, unless the power line is properly fused, it is possible for the power line to overheat and cause a fire. If the power is supplied by a home generator, overloading the line reduces the output voltage and may shorten the life of the generator. There are many series-parallel and parallel-series combinations used in radio- and television-receiver circuits. You will meet many of them in later lessons.

SUMMARY

The three rules for series circuits are:

1. In a series circuit, the same current flows in each part of the circuit.
2. The total resistance of two or more resistors connected in series is equal to the sum of the individual resistances.
3. The sum of the voltage drops in a series circuit is equal to the applied voltage.

The laws governing parallel circuits are:

1. The voltage across each branch of a parallel circuit is the same and is equal to the applied voltage.
2. The total current in a parallel circuit is equal to the sum of the currents flowing in

the individual branches.

3. The total resistance of equal resistors in parallel is equal to the value of one of the resistors divided by the number of them connected in parallel.

4. The total resistance of any two resistors connected in parallel is equal to their product divided by their sum. That is:

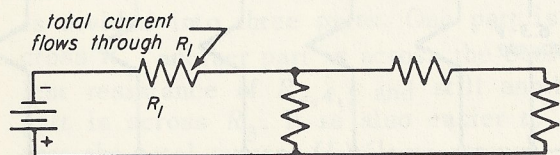
$$R_t = \frac{\text{Product}}{\text{Sum}} = \frac{R_1 \times R_2}{R_1 + R_2}$$

5. The total resistance of a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual resistances, which is written:

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \text{ etc.}}$$

To solve d-c circuits, it is necessary for you to understand Ohm's Law and the rules given above. With this understanding, series and parallel circuits are readily solved. Without this understanding, you cannot know what rules or which Ohm's Law formula to apply to a circuit you are studying. To solve parallel-series and series-parallel circuits, use Ohm's Law; use the rules for series circuits and the rules for parallel circuits, where they apply.

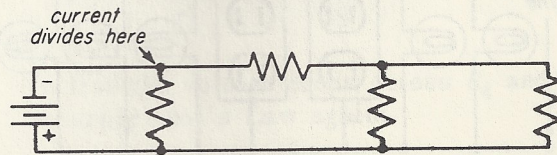
One easy way to tell the difference between a series-parallel or parallel-series circuit is as follows: Examine the circuit to see whether or not the total current from the battery or other voltage source flows through any one resistor in the circuit. If the total current flows through at least one resistor, as it does through R_1 in Fig. 8-16a, then the circuit is series-parallel. If no resistor receives the total current, as in Fig. 8-16b, then the circuit is parallel-series.



(a)

Series-Parallel

Fig. 8-16



(b)

Parallel-Series